3-body calculations for ^{6}He and ^{11}Li β decay into the continuum

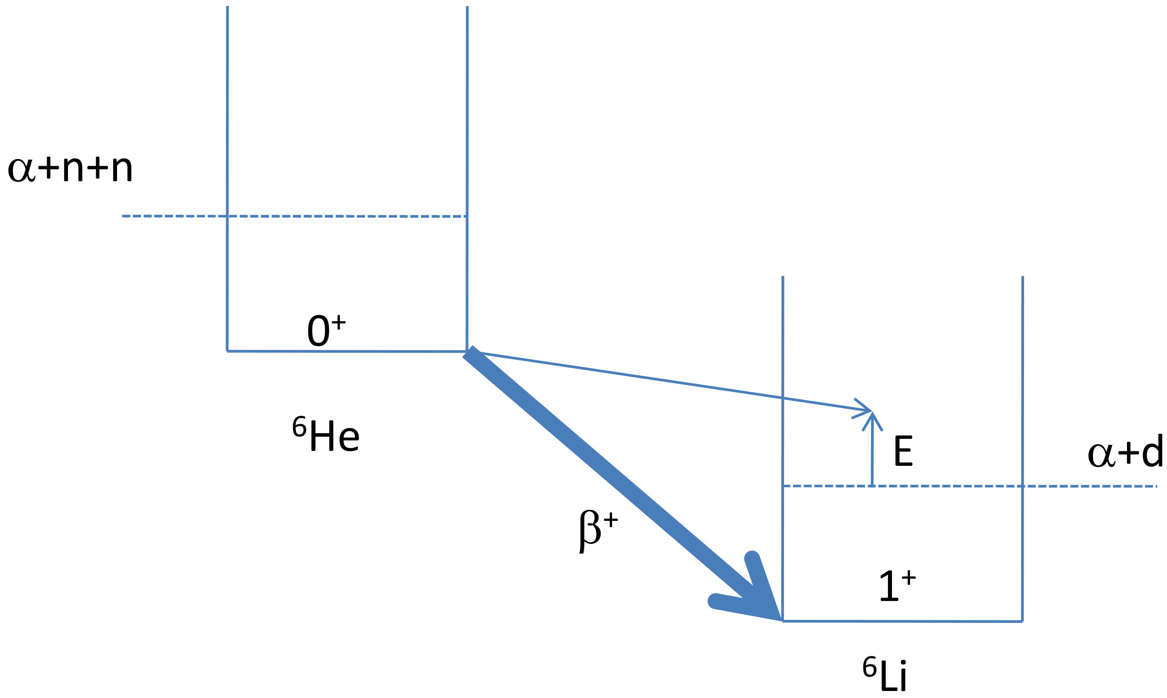
P. Descouvemont

In collaboration with D. Baye, E. Tursunov

3 papers

- $^{6}He \rightarrow \alpha + d + e^{+} + \nu$: Phys. Rev. C 73 (2006) 014303
- $^{11}Li \rightarrow {}^{9}Li + d + e^{+} + \nu$: Phys. Rev. C 74 (2006) 064302
- $^{6}Li(0^{+};T=1) \rightarrow \alpha + d + \gamma$: virtually submitted

^{6}He → α + d + e^+ + ν : probes the halo structure

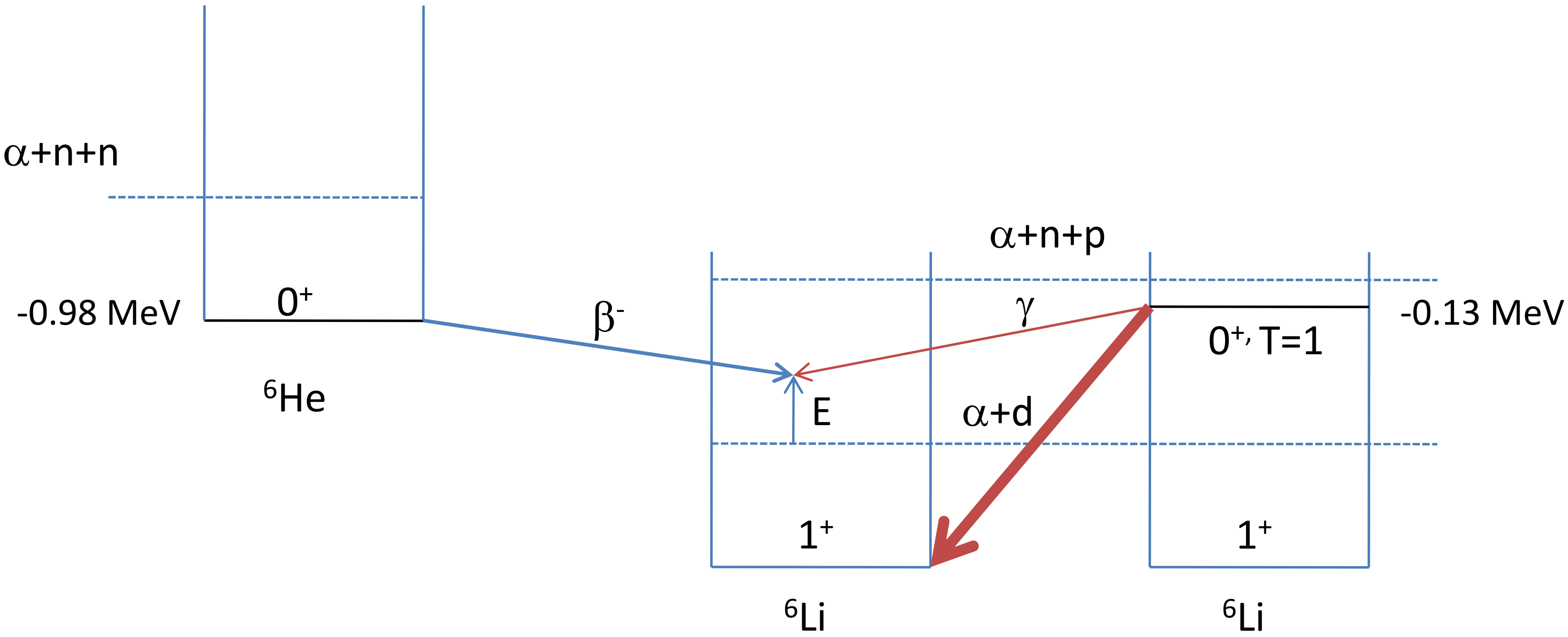


β decay: Gamow-Teller transition $0^+ \rightarrow 1^+$ to the ^{6}Li ground state
the α+d continuum (*s* wave)

matrix element: $<^6\mathrm{Li} \mid \sigma\tau^- \mid ^6\mathrm{He}>$ g.s.: probes short-range part of ^{6}He

$<\alpha + \mathrm{d} \mid \sigma\tau^- \mid ^6\mathrm{He}>$ α+d: probes the halo (low α+d energies)

^{6}Li (0+)→ α + d + γ : M1 transition



0^+; T=1 state in ^{6}Li: decay to α+d forbidden : $0^+ \neq 1^+ \oplus 0^+$ → parity forbidden
→ below the α+n+p threshold → bound (isobaric analog of ^{6}He)
→ γ decay (M1) possible

^{6}He β decay $< \alpha + \mathrm{d} \,|\, \sigma\tau^- \,|\, {}^6\mathrm{He} >$ Gamow –Teller transition

^{6}Li γ decay $< \alpha + \mathrm{d} \,|\, \sigma\tau^0 (+L\tau^0) \,|\, {}^6\mathrm{Li}(0^+) >$ M1 gamma transition

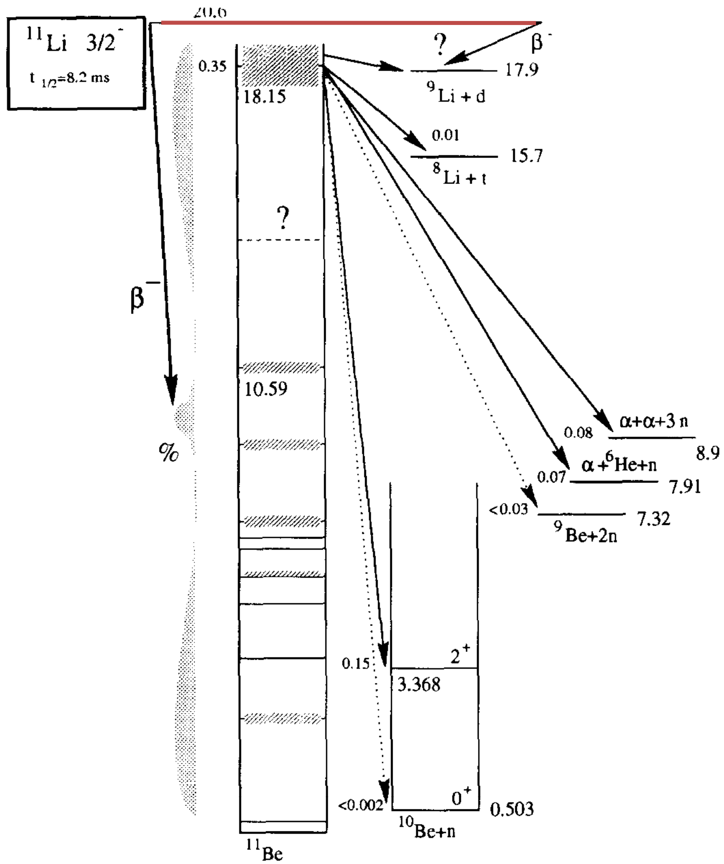
➔ test of the halo structure in $^{6}Li(0^{+})$
➔ competes with parity violation

Calculation: Grigorenko et al. (Phys. At. Nucl. 61 (1998) 1472)

Experiment: Mukha et al. (Louvain-la-Neuve + KUL)

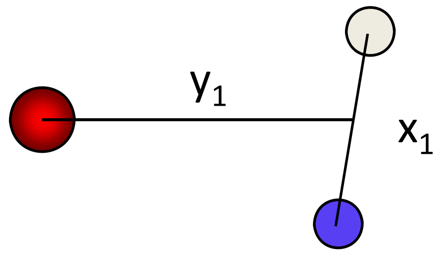
$^{11}Li \rightarrow {}^{9}Li + d + e^{+} + \nu$

- probes the halo structure of ^{11}Li
- different from ^{6}He: many open channels
- resonance in ^{11}Be?



Exp: M. Borge et al., Nucl. Phys. A613 (1997) 199
KUL- Triumf

The 3-body model



Jacobi coordinates x_1, y_1

3 sets (x_i, y_i), $i=1,2,3$

Hyperspherical coordinates:

$$\rho^2 = x_1^2 + y_1^2 = x_2^2 + y_2^2 = x_3^2 + y_3^2$$
$$\alpha_i = \arctan \frac{y_i}{x_i}$$
$$\Omega_{x_i}, \ \Omega_{y_i}$$

} 6 coordinates

Hamiltonian:

$$H = T_1 + T_2 + T_3 + V_{12} + V_{13} + V_{23}$$ to be expressed in $(\rho, \Omega_{x_i}, \Omega_{y_i}, \alpha_i)$

Wave functions

$$\Psi^{JM\pi}(\rho, \Omega_5) = \rho^{-5/2} \sum_{\gamma K} \chi^{J\pi}_{\gamma K}(\rho) \ \times \ \mathcal{Y}^{JM}_{\gamma K}(\Omega_5)$$

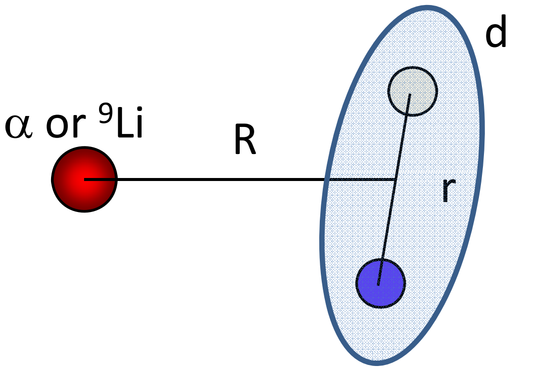
K=hypermomentum
γ=other quantum numbers

functions $\chi^{J\pi}(\rho)$ obtained from a set of differential equations

Nucleus-nucleus potentials

- NN: Minnesota (deuteron binding energy, low energy phase shifts)
- α+N: Voronchev et al., Few-Body Syst. 16 (1995) 191
  reproduces the α+n phase shifts
- ^{9}Li+n: Thompson and Zhukov, Phys. Rev. C49 (1994) 1904
  reproduces the scattering length

Two-body model



Factorization:

$$\Psi_{\alpha d}(E, r, R) = u_d(r)\,\Psi_{\alpha d}(E; R)$$

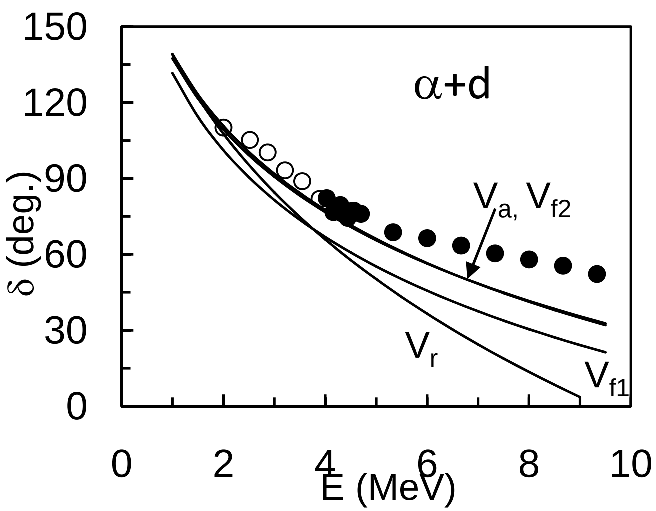
deuteron w.f. ($u_d(r)$)

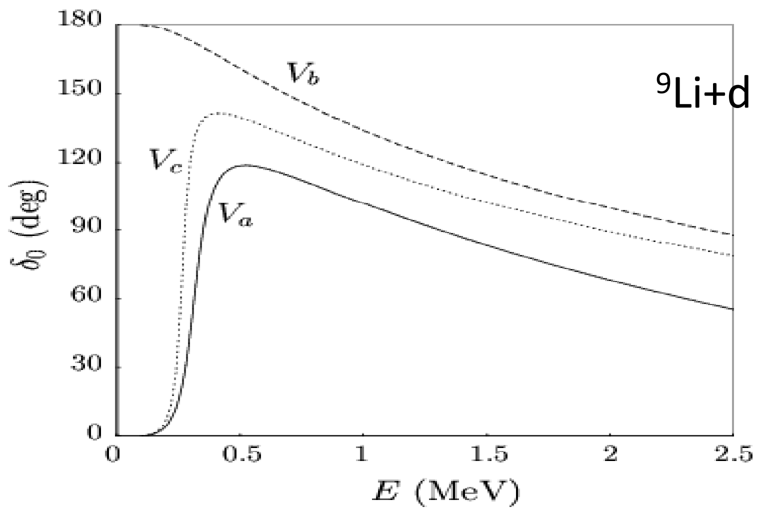
α–d relative w.f. ($\Psi_{\alpha d}(E; R)$)

α+d potential

^{9}Li+d potential

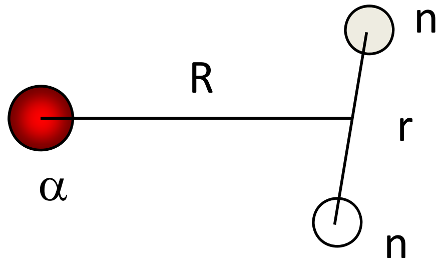
} various forms to test the sensitivity

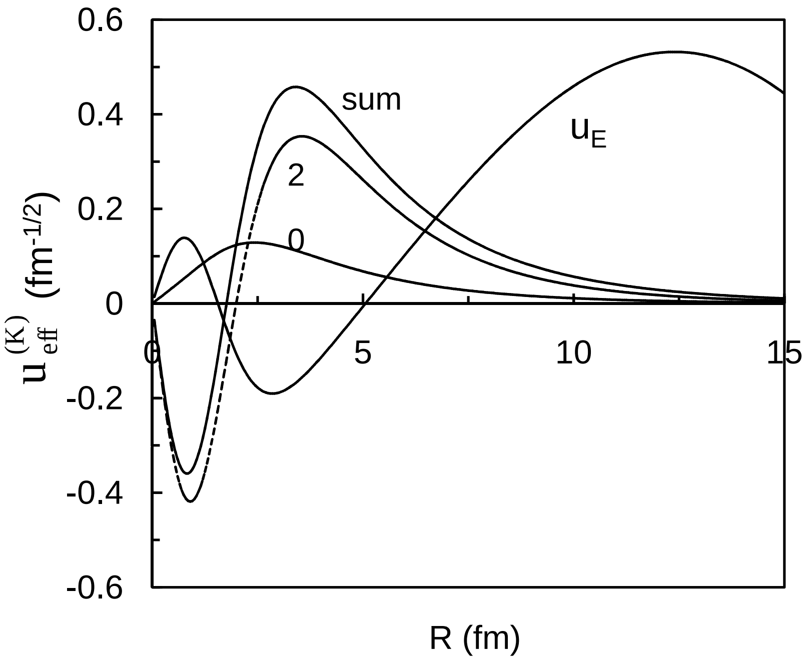


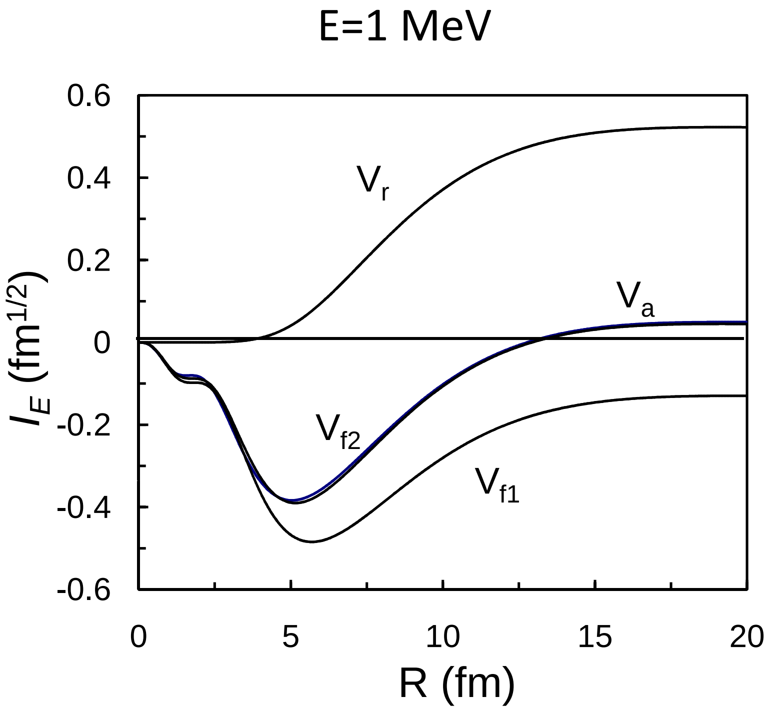


Results on $^6He \rightarrow \alpha + d + e^+ + \nu$

$$
\begin{aligned}
\Psi^{^6He} &= \sum_K \Psi_K^{^6He} \\
<\sigma\tau^-> &= <\Psi_{\alpha d}(R) u_d(r) | \Psi^{^6He}(r, R)> \\
&= <\Psi_{\alpha d}(R) | \sum_K u_{eff}^K(R)> \\
&= \lim_{R\to\infty} I_E(R)
\end{aligned}
$$

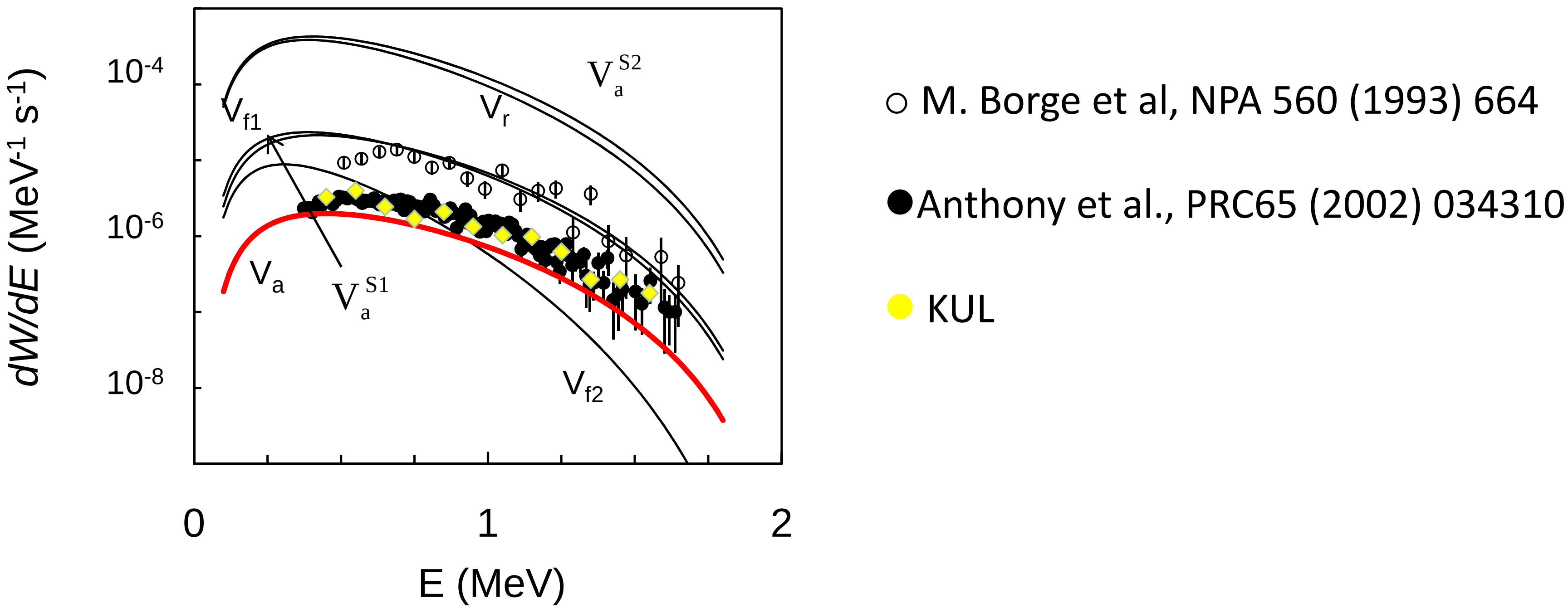






inner part ~halo part → cancellation

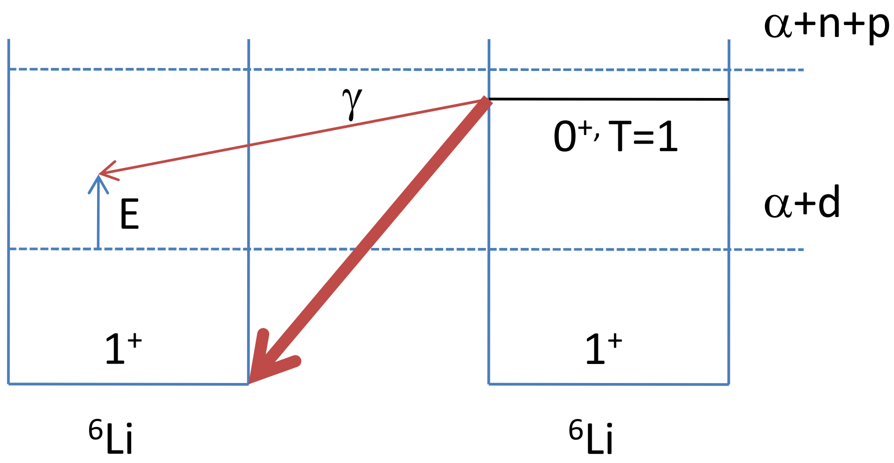
Transition probability



W (10^6 s^{-1})

potential	V_a	V_{f1}	V_{f2}	V_r	Borge	Anthony
E>0	1.44	18.52	4.28	250.85		2.2 ± 1.1
E>0.37 MeV	1.14	13.43	2.45	188.87	7.6 ± 0.6	1.5 ± 0.8

Results on ^{6}Li(0^+;T=1)→α + d + γ



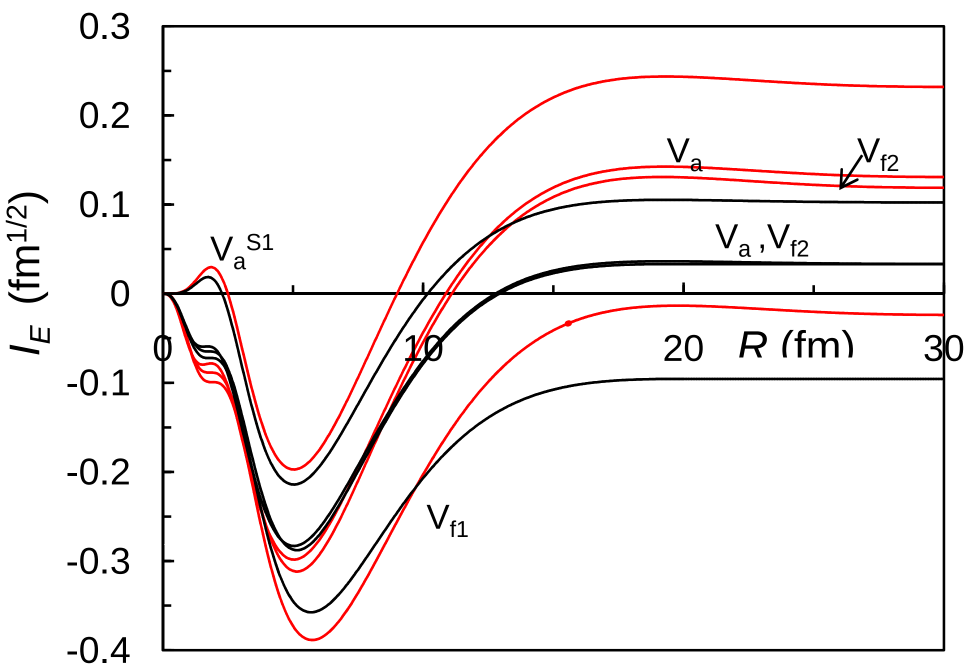
M1 operator: $(\sigma+L)\tau^0$
(orbital part small: ~2-3 %)

test of the calculation: bound-state properties

	Theory	Experiment
μ (1^+)	0.86 μ_N	0.82 μ_N
Γ_γ ($0^+ \rightarrow 1^+$)	7.5 eV	8.19 $\pm$ 0.17 eV

Results on $^6Li(0^+;T=1) \rightarrow \alpha + d + \gamma$

Transition to the continuum (E=1 MeV)



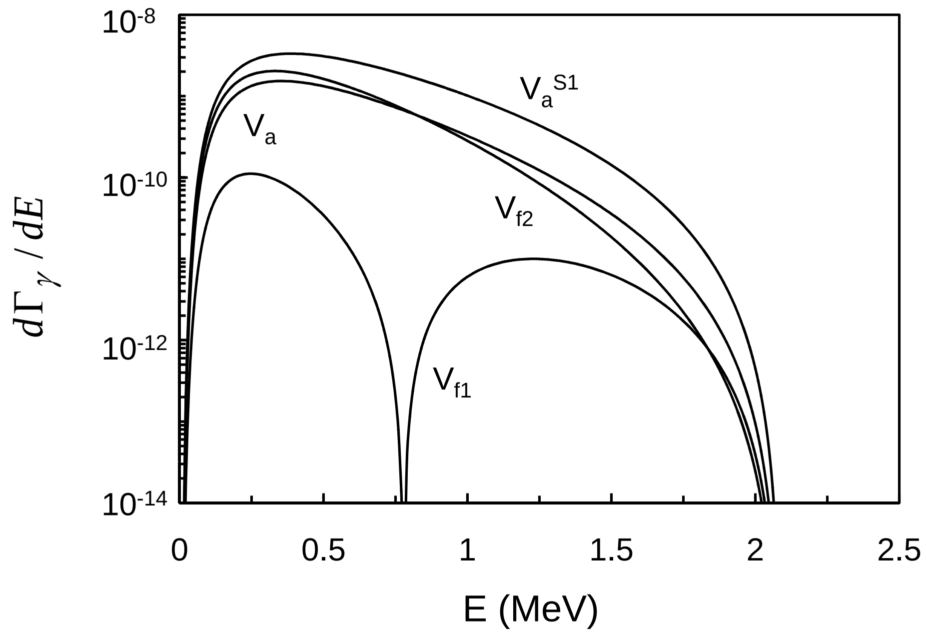
- ____ ^6He
  ____ ^6Li

- internal parts similar

- halo part more important
  → **cancellation effect weaker**

Results on $^6Li(0^+;T=1) \rightarrow \alpha + d + \gamma$

Spectrum

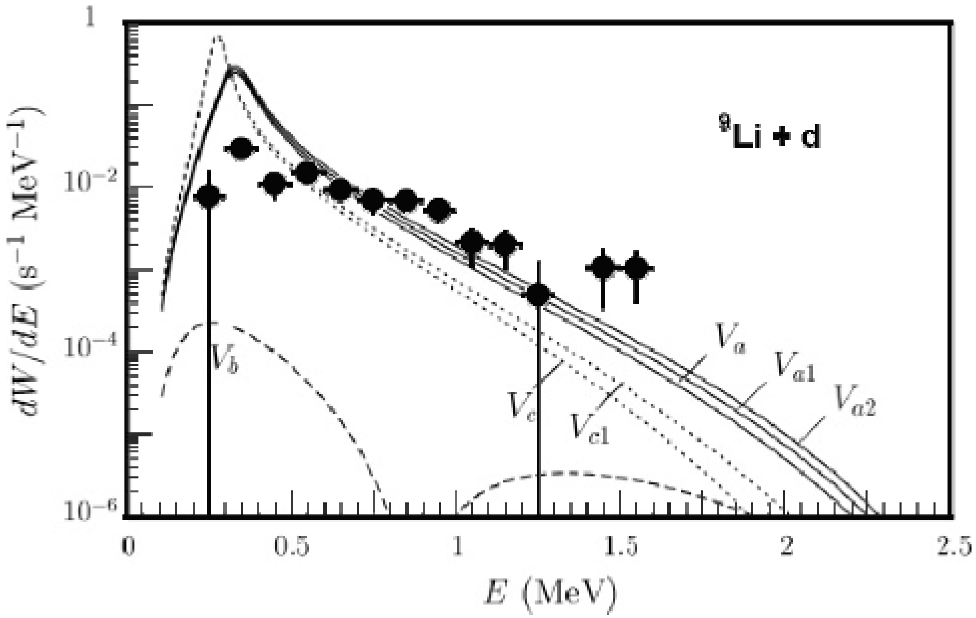


Transitions to the continuum		
Potential	Γ_γ (meV)	B.R. (10^{-4})
V_a (good)	0.90	1.2
V_{f1} (poor)	0.04	0.05
V_{f2} (good)	1.08	1.4
V_S (poor)	2.27	3.0

→ B.R. ~ 1.3×10^{-4}

larger than for ^6He β decay
observable experimentally

Results on $^{11}Li \rightarrow {}^{9}Li + d + e^{+} + \nu$



No cancellation effect
→ weaker sensitivity to potential

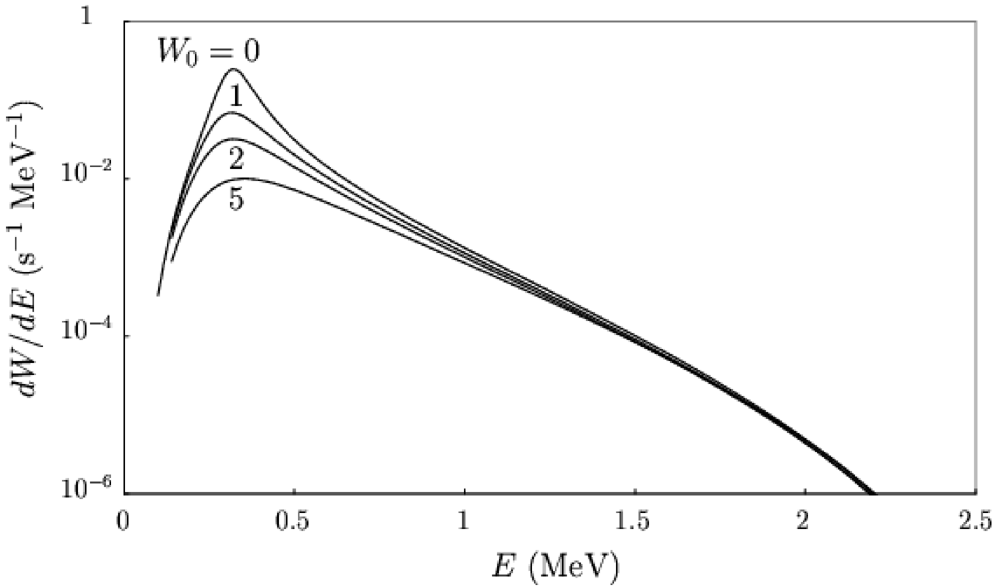
Transition probability (10^{-3} s^{-1})	
Potential	W
V_a (*s* resonance in ^{11}Be)	38.1
V_b (no resonance)	0.072
V_c (*s* resonance in ^{11}Be)	59.7
exp (ISOLDE)	**12 ± 2**

➔ s resonance in ^{11}Be necessary for the order of magnitude

Results on $^{11}Li \rightarrow {}^{9}Li + d + e^{+} + \nu$

Influence of absorption: previous results with **real** potentials

→ introduction of a complex part (with amplitude W_0)



main effect near the resonance energy

Transition prob., exp=(12±2)x 10^{-3}	
W_0=0	38.1 x 10^{-3}
W_0=1 MeV	16.7x 10^{-3}
W_0=2 MeV	9.9 x 10^{-3}
W_0=5 MeV	4.4 x 10^{-3}

Conclusions

- These processes need
  - accurate data
  - accurate models (K expansion up to K~24-30)

- Sensitive to the halo structure

- $^{6}He \rightarrow \alpha + d + e^{+} + \nu$
  - small branching ratio is a direct evidence for the halo (cancellation)
  - many data (CERN, Triumf, KUL-UCL)

- $^{11}Li \rightarrow {}^{9}Li + d + e^{+} + \nu$
  - No cancellation effect
  - Needs an s-wave resonance in ^{11}Be
  - Data from CERN, Triumf-KUL?

- $^{6}Li(0^{+};T=1) \rightarrow \alpha + d + \gamma$
  - Halo very extended → dominant part
  - Data from LLN-KUL???